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ORIGINAL ARTICLE

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A geospatial investigation of cloud-to-ground lightning strikes during pre-monsoon and post-monsoon seasons in Dakshina Kannada district during the years 2021 to 2023

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ABSTRACT

Background: Lightning is a natural phenomenon that poses significant hazards in regions like Dakshina Kannada, India. This coastal district, located between the Arabian Sea and the Western Ghats, experiences frequent lightning, especially during the pre-monsoon and monsoon seasons, necessitating a deeper understanding of its patterns for effective disaster management. This study investigates the spatial and temporal distribution of cloud-to-ground (CG) lightning strikes in Dakshina Kannada from 2021 to 2023, focusing on the correlation between land use and land cover (LULC) changes and lightning density.

Methods: Data were collected from the Karnataka State Natural Disaster Monitoring Centre (KSNDMC) and other sources. Geographic Information System (GIS) tools, particularly ArcGIS 10.8, were used to create density maps, choropleth maps, and spatial overlays. LULC maps were derived from Sentinel-2A satellite imagery to analyze seasonal trends and spatial correlations with lightning strikes.

Results: High lightning density was observed in Kadaba, Belthangadi, and Sullia, especially during the pre-monsoon months. Forested areas with moisture-laden trees were more prone to lightning strikes, while urban areas showed lower densities. Seasonal analysis highlighted increased lightning activity during the pre-monsoon season.

Conclusions: The study provides insights into lightning patterns in Dakshina Kannada, emphasizing the influence of topography and LULC on lightning distribution. These findings support targeted disaster management strategies, including early warning systems and public education campaigns. Future research should examine the impact of urbanization and climate change on lightning patterns.

KEYWORDS

Lightning events; LULC analysis; GIS mapping; Seasonal variations; Dakshina Kannada

ARTICLE HISTORY

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Introduction

Lightning is an ancient natural phenomenon characterized by a massive spark of static electricity discharging between regions with differing electric charges in the atmosphere. Despite being widely observed, it remains one of the least understood natural phenomena. Lightning occurs in various forms, including cloud-to-ground (CG), cloud-to-cloud (CC), intra-cloud (IC), cloud-to-air (CA), ball lightning, and heat lightning. Among these, CG lightning is the most familiar and visible type, where an electric discharge travels from a thundercloud to the Earth's surface. CG lightning can be negative (-CG), which is more common, or positive (+CG), which is less frequent. Other types like CC and IC lightning occur within or between clouds, often appearing as bright flashes or sheet lightning [1].

Factors such as ground elevation, latitude, and the presence of water bodies significantly affect lightning distribution. Areas with frequent thunderstorms, such as the central plains of the United States, are particularly prone to lightning. The Indian subcontinent, known for its active convection, is a prominent global lightning hotspot. Lightning also plays a role in the Earth's nitrogen cycle by converting atmospheric nitrogen into nitrogen oxides that nourish plant life [2]. Despite centuries of study, lightning's unpredictability limits a complete understanding of its behavior, though it is known that about 70% of lightning occurs over land in the tropics, with CG lightning accounting for only 25% of all lightning flashes worldwide.

A coastal district in Karnataka, India's southwest is called Dakshina Kannada. Its location between the Arabian Sea and the Western Ghats creates a unique setting for studying lightning patterns [3]. Because of the high humidity, huge temperature changes, and frequent thunderstorms, this region is particularly vulnerable to lightning strikes during the pre-monsoon and monsoon seasons. Understanding Dakshina Kannada lightning patterns is vital for effective risk assessment, mitigation, and disaster management. Examining these patterns can help authorities reduce the danger to people, property, and infrastructure by better anticipating and responding to lightning-related disasters.

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Despite the frequency of lightning strikes in Dakshina Kannada, little information is available about their spatial and temporal distribution, as well as their relationship with changes in land use and land cover (LULC). Current lightning forecast systems lack adequate detail in these areas, and the impact of LULC modifications on lightning distribution is unclear. This gap impedes efficient planning and mitigation efforts, underlining the need for a thorough investigation to better understand these trends [4].

The research on lightning patterns in Dakshina Kannada is limited. While there has been research on lightning activity around the world and in other parts of India, few have focused on the association between lightning and LULC changes in this region [5]. There is little research on how diverse land cover types, such as forests, urban areas, and bodies of water, affect lightning frequency and dispersion. Furthermore, there is a lack of awareness of the temporal trends in lightning activity and their implications for risk management and disaster planning in Dakshina Kannada.

The purpose of this research is to perform a comprehensive geospatial examination of cloud-to-ground lightning strikes in Dakshina Kannada district during the pre- and post-monsoon seasons from 2021 to 2023. The goals are to map the spatial and temporal distribution of lightning strikes, examine the relationship between LULC types and lightning density, and assess how seasonal variations affect lightning activity [6]. The study will use Geographic Information System (GIS) techniques to generate precise maps and pinpoint lightning hotspots. The findings will help to improve our understanding of lightning trends in Dakshina Kannada and enable the creation of safer and more resilient communities.

Literature Review

Materials

Lightning is a highly changeable atmospheric phenomenon that necessitates significant data collecting over broad areas and over many years to provide trustworthy estimates of its activity. Lightning flash density, defined as the number of flashes occurring across a unit area in a given amount of time, is an important statistical term for describing lightning. Lightning most commonly occurs in cumulonimbus clouds, but it can also exist in stratiform clouds, snowstorms, dust storms, and volcanic emissions. It can strike within a cloud, between clouds, from a cloud to the air, or from a cloud to the ground. The spatial and temporal distribution of lightning is influenced by the distribution of positive and negative charges within clouds [7]. Thunderstorm distribution in India is largely linked to overall atmospheric circulation. Northwest India, for example, has a high density of lightning during the monsoon and pre-monsoon seasons, but locations such as the Western Ghats have a decreasing trend [8].

Lightning activity is heavily influenced by topography and climate conditions. According to studies conducted in Colorado, elevation closely corresponds with lightning occurrence, with a significant increase in stroke density above 3,200 meters, particularly on high mountain tops. Similarly, the Western Ghats of India influence lightning distribution by influencing southwest monsoon airflow, where convective activity, precipitation, aerosols, and terrain all contribute to lightning production [9].

Changes in land use and cover (LULC), such as urbanization, have an impact on local weather and lightning. Urban heat islands (UHI) caused by increased temperatures in cities promote convective storm development, impacting lightning patterns. Increased lightning activity in Taipei has been related with urbanization, affecting convection due to changes in surface temperature and air pollution. [10].

Geospatial technology, such as Geographic Information Systems (GIS) and remote sensing, are critical for studying lightning patterns and aiding disaster response. GIS has been used to map lightning density and detect hotspots by comparing them to topographical characteristics such as valleys and mountain ridges. Remote sensing data is used to detect lightning patterns and hotspots, such as those in the Himalayas and eastern India. These technologies are vital for creating early warning systems and influencing risk mitigation strategies in places with significant lightning activity [11].

Study Area

Geographical context

Dakshina Kannada, commonly known as South Canara, is a coastal district in the southwestern Indian state of Karnataka, having its headquarters in Mangalore. It has an area of 4,859 square kilometers and is bounded by the Arabian Sea to the west, the Western Ghats to the east, Udupi district to the north, and Kerala to the south. This location forms a unique environment where the sea meets the mountains, with a variety of weather variables. The district has a tropical monsoon climate, with high rainfall during monsoon season. The Western Ghats, a worldwide biodiversity hotspot, influence the region's geography, reaching elevations of 1,115 meters. The Ghats are the source of major rivers such as the Netravathi, Kumaradhara, and Gurupura, which influence the hydrological patterns of the region(Figure 1) [12].

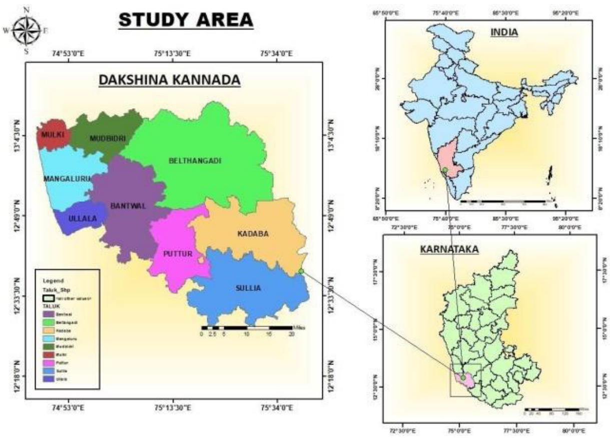

Figure 1. Map showing study area.

LULC characteristics

The district includes a diverse range of land use and land cover (LULC) categories, such as agricultural lands, forests, urban areas, and aquatic bodies. Coastal lowlands near the Arabian Sea are ideal for extensive crop cultivation, including paddy, coconut, and areca nuts. The Western Ghats, located further inland, are characterized by dense semi-evergreen, moist deciduous, and tropical evergreen forests. Urban areas, around Mangalore, have

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grown dramatically, resulting in more densely populated zones. Water bodies, like rivers, streams, and ponds, are critical for irrigation and preserving ecological equilibrium (Figures 2 and 3) [13].

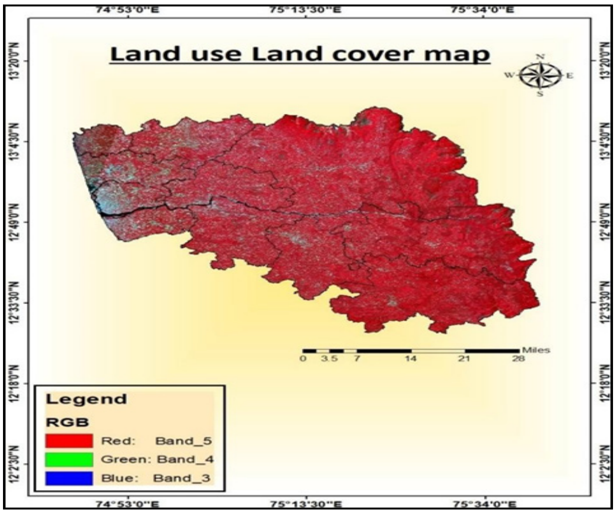

Figure 2. Landsat-8 imagery; band 5,4,3(Infra-Red).

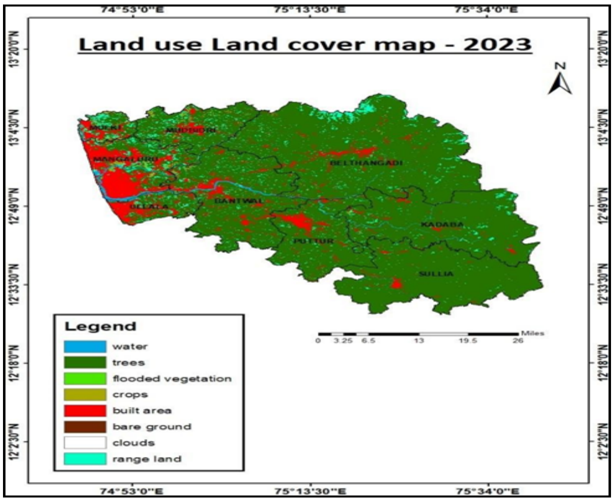

Figure 3. LULC map (Sentinel-2A imagery) of Dakshina Kannada district-2023.

Relevance to study

Dakshina Kannada is ideal for studying lightning patterns due to its distinct geographical features and changing environment. The district's varied LULC types, which include forests, agricultural lands, and urban areas, create different atmospheric conditions that influence lightning activity. Understanding how these factors affect lightning is critical for disaster preparedness [14]. In recent years, Dakshina Kannada has seen a significant increase in cloud-to-ground lightning incidents in recent years.

Data and Methodology

Data collection

The study uses secondary data from various places to investigate the spatial and temporal distribution of cloud-to-ground (C-G) lightning in Dakshina Kannada district, Karnataka, India. The primary source of lightning data is the Karnataka State Natural Disaster Monitoring Centre (KSNDMC), which is an autonomous entity within the Karnataka Revenue Department. The KSNDMC maintains a network of lightning detection sensors around the state that offer real-time data on thunderstorms and lightning, including cloud-to-ground and cloud-to-cloud strikes (Figure 4). This data was critical for mapping lightning density and identifying high-risk regions throughout the district. In addition, the Taluk boundary shapefile for Dakshina Kannada was collected from the KSNDMC to precisely outline administrative borders during geographical analysis [15].

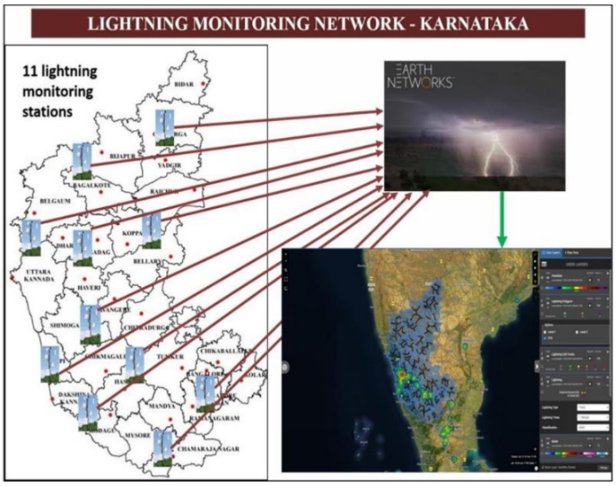

Figure 4. Lightning Network in Karnataka (KSNDMC).

Furthermore, the village border shapefile for Dakshina Kannada was obtained from the Karnataka Geographic Information System (K-GIS) portal, a government program that provides geospatial data for a variety of purposes. The Digital Elevation Model (DEM) data required to comprehend the region's topography was obtained from the Shuttle Radar Topography Mission (SRTM) dataset, which is available through the USGS Earth Explorer platform [16]. This DEM data was used to evaluate elevation changes and their effect on lightning patterns.

The study also required Land Use and Land Cover (LULC) data, which was obtained from Sentinel-2A satellite imagery provided by ESRI Inc., a well-known manufacturer of geographic information system (GIS) software and geodatabase management applications. Sentinel-2A imagery with a resolution of 10 meters produced precise LULC maps, which were crucial in assessing the impact of various land use types on lightning activity. The images were examined using ERDAS Imagine, a remote sensing software, which allowed layer stacking and other advanced image processing techniques [17].

GIS tools and techniques

This study's spatial analysis was mostly carried out using ArcGIS 10.8, a robust GIS software made by ESRI. ArcGIS 10.8 provides powerful tools for generating, modifying, and analyzing geographic data, which has been used to create precise maps and visualizations of lightning distribution in Dakshina Kannada. The software was used to build lightning density maps, choropleth maps, and spatial overlays to view and evaluate lightning patterns and their relationship with different LULC kinds [18].

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The point density function in ArcGIS was used to calculate the number of lightning strikes per square kilometer. This was accomplished with the Spatial Analyst tool, which is part of ArcGIS' range of geoprocessing tools that support a variety of spatial analysis functions. The software's geodatabase structure enabled the smooth integration of numerous data layers, including lightning incidents, administrative boundaries, and LULC maps, improving spatial analytical accuracy and dependability. Furthermore, Microsoft Excel was used to filter, sort, and convert data to CSV format, ensuring interoperability with ArcGIS [19].

Formula for lightning Density

$$\text{Lightning density} = \frac{\textit{Number of C-G lightning strikes per square kilometer}}{\textit{Area in square kilometre}}$$

The Sentinel-2A satellite imagery was also processed using ERDAS Imagine. The software's layer stacking feature, which combines many single-band images into a multi-band composite, was critical for producing detailed LULC maps. This technique allowed the researchers to precisely define land cover types and examine their impact on lightning patterns [20].

Data processing steps

The methodology commenced with the collection of pre-monsoon and post-monsoon lightning data from 2021 to 2023, as well as the Taluk boundary shapefile of Dakshina Kannada. The data was first cleaned and pre-processed in Microsoft Excel, where it was filtered and sorted according to the study's specifications. This method included eliminating any superfluous or extraneous data points and transforming the data to a CSV format suitable for use in ArcGIS [21].

The next step was to import the cleansed data into ArcGIS 10.8. The Taluk boundary shapefile and lightning data were imported into the ArcGIS environment. The latitude and longitude data from each lightning strike were utilized to generate point data, which was then transformed into a point feature class. To assure spatial correctness, the data was reprojected using the Data Management tool in ArcGIS, aligning the data to a consistent coordinate system [19].

The lightning density maps were generated using the point density tool in ArcGIS's Spatial Analyst extension. This program calculates the density of point features (lightning strikes) in a given area (per square kilometer). The processing extent and mask were set to the Taluk boundary shapefile to concentrate the analysis on Dakshina Kannada. The resulting density maps were then formatted with appropriate iconography, grids, and legends to clearly depict the distribution and intensity of lightning occurrences across the district [16].

In addition to density maps, choropleth maps were generated to show the overall number of C-G lightning incidents in each Taluk. This technique entailed combining the lightning data with the Taluk boundary shapefile via a shared attribute field, such as the Taluk name. The iconography was altered to show the variability in lightning incidences across different Taluks, allowing for a comparative examination of high and low-risk locations [21].

The study also created LULC maps of Dakshina Kannada from 2021 to 2023 using Sentinel-2A satellite images (Figure 5). These pictures were imported into ArcGIS, and the Taluk border shapefile was superimposed to add context. The spatial analyst tool was used to extract the LULC data by applying a mask of the Taluk border, and the class definitions were changed depending on the number provided and ESRI's color coding recommendations [22].

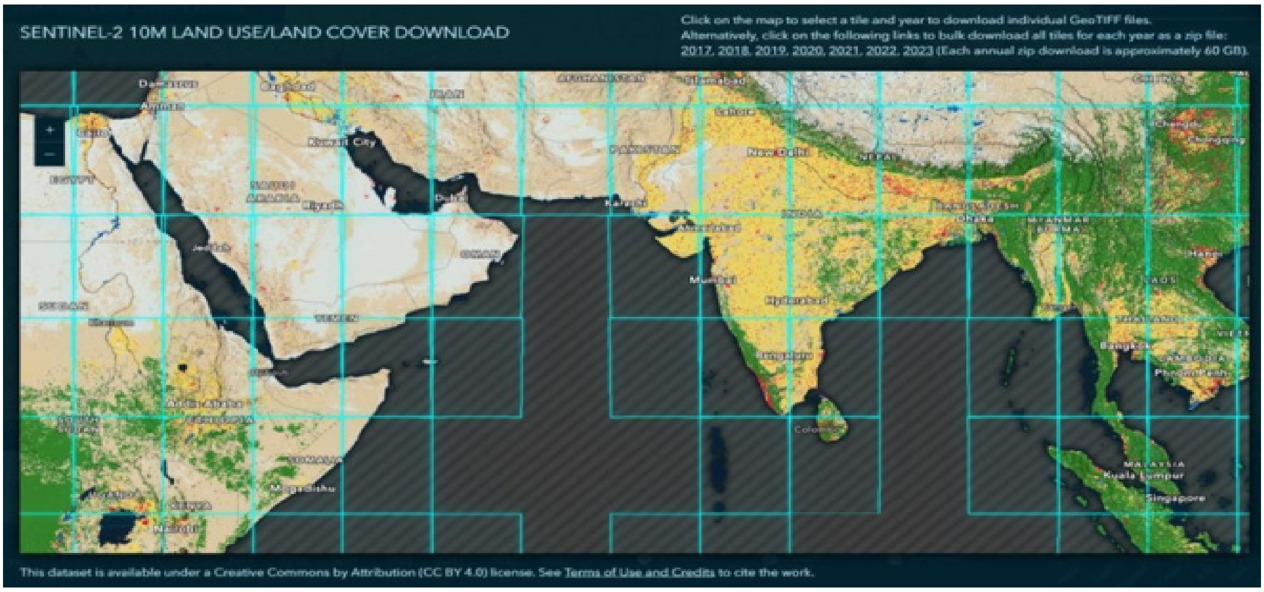

Figure 5. Sentinel-2 LULC Imagery Downloader.

To further comprehend the relationship between land use classifications and lightning activity, a spatial overlay of the LULC map and the lightning density map was used. This included loading both the lightning density map and the LULC map into ArcGIS and confirming that they were in suitable formats such as GeoTIFF. The Taluk boundary shapefile was utilized as a reference to verify that the data layers were accurately aligned. The layers' transparency, contrast, and brightness were changed to improve visibility, providing a clear comprehension of the spatial association between LULC changes and lightning events [5].

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Statistical analysis

Basic statistical approaches were used to find trends and patterns in lightning dispersion. The density of lightning strikes was computed using spatial data and evaluated to discover the relationship between LULC changes and lightning activity. The study also used Microsoft Excel for early statistical analysis, such as calculating averages, finding outliers, and making graphs to show trends. This statistical analysis influenced the study's conclusions about the impact of LULC changes on lightning patterns in Dakshina Kannada [23].

The spatial study and statistical results revealed that certain locations of Dakshina Kannada, notably those with extensive urbanization or deforestation, had greater lightning densities. Taluks such as Mangalore and Belthangady, which have seen significant land use changes, have shown higher lightning activity than more rural or forested areas. This implies that LULC changes, particularly those related to urban expansion and forestry, contribute to the frequency and distribution of lightning strikes in the district [24].

The study's findings have significant implications for disaster management and urban planning in Dakshina Kannada. Local governments can improve lightning strike mitigation by identifying high-risk regions and understanding the elements that contribute to lightning activity. Furthermore, this study emphasizes the need of sustainable land management methods in minimizing the harmful consequences of LULC changes on local weather patterns [25].

Results

Lightning density analysis

The analysis of lightning density maps for 2021, 2022, and 2023 demonstrates significant variances in lightning activity across Dakshina Kannada district's several taluks. These maps provide light on locations with high lightning density, indicating certain regions that are more susceptible to cloud-to-ground lightning strikes [26].

In 2021, Belthangadi taluk had the most lightning events, reaching 14,014. Kadaba came in second with 10,311 incidences, followed by Sullia with 8,206 (Figure 6). The density map for 2021 shows that these taluks saw more than 14 lightning strikes per square kilometer. Hotspots were observed in villages such as Shiradi, Rekya, Kyla, Savanuru, and Bantra Hill in Kadaba; Kaliya, Marodi, Dharmastala, and Naravi in Belthangadi; and Naikuru and Aivarnadu in Sullia [27]. The data highlights that these areas are highly vulnerable to lightning, particularly during pre-monsoon and post-monsoon seasons. In contrast, the coastal taluks of Mulki and Ullala reported the fewest lightning events, with lower frequencies, indicating these regions are less prone to lightning strikes (Table 1).

Table 1. Current commercially available ultrasound contrast agents.

Cloud to ground lightning event of DK district in 2021								
					Months			Total no. Of
SL.NO	Taluk	March	April	May	October	November	December	events
1	Mangaluru	211	928	211	18	1	0	1369
2	Bantwal	745	1724	776	145	0	0	3390
3	Belthangadi	324	4545	2614	343	0	0	7826
4	Puttur	133	633	1062	122	1	0	1951
5	Sullia	17	2196	1551	287	0	0	4051
6	Mudbidri	149	944	436	84	0	0	1613
7	Ullala	245	365	137	6	0	0	753
8	Mulki	2	152	27	3	0	0	184
9	Kadaba	515	1987	1920	383	0	0	4805
	Total	2341	13474	8734	1391	2	0	25942

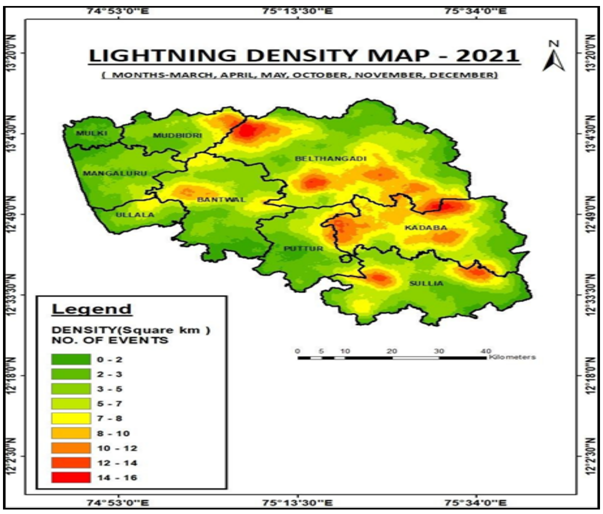

Figure 6. Lightning density map of Dakshina Kannada in 2021.

In 2022, the overall lightning density in the district declined (Figure 7). Kadaba taluk continued to exhibit a relatively high number of lightning strikes, with densities of 5-7 strikes per square kilometer, especially in villages like Bilinele, Kombar, and Aithuru. Belthangadi and Sullia taluks followed with similar densities in areas such as Dharmastala, Mogru, and Jalsuru [28]. The reduced lightning density in 2022 suggests a decrease in overall lightning activity compared to 2021 (Table 2).

In 2023, the lightning density analysis indicated a moderate increase in activity relative to 2022 (Figure 8). Kadaba taluk again had the highest density (7-9 strikes per km²), with significant hotspots in Enekallu, Aithuru, and Kodimala. Belthangadi and Sullia also recorded moderate to high lightning density. The persistent high lightning density in these taluks over three years highlights a consistent pattern of increased lightning activity in these regions [29] (Table 3).

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Table 2. C-G lightning events of Dakshina Kannada in 2022.

Cloud to ground lightning event of DK district in 2022								
Sl.no	Taluk	Months March	April	May	October	November	December	Total no. Of events
1	Mangaluru	42	53	260	19	94	0	468
2	Bantwal	181	158	456	46	80	1	922
3	Belthangadi	531	812	756	208	87	15	2409
4	Puttur	75	280	659	31	13	0	1058
5	Sullia	196	918	538	30	95	0	1777
6	Mudbidri	19	242	291	66	34	0	652
7	Ullala	2	87	12	4	5	0	110
8	Mulki	0	10	14	2	18	0	44
9	Kadaba	377	749	618	142	126	0	2012
	Total	1423	3309	3604	548	552	16	9452

Table 3. C-G lightning events of Dakshina Kannada in 2023.

Cloud to ground lightning event of DK district in 2023								
Sl.no	Taluk	Months March	April	May	October	November	December	Total no.of events
1	Mangaluru	0	1	55	200	99	0	355
2	Bantwal	0	4	227	774	189	3	1197
3	Belthangadi	3	325	1265	1572	609	5	3779
4	Puttur	0	2	622	542	305	0	1471
5	Sullia	0	209	1067	680	420	2	2378
6	Mudbidri	0	131	54	242	146	17	590
7	Ullala	0	0	58	141	21	0	220
8	Mulki	0	0	1	25	47	0	73
9	Kadaba	1	361	1330	1429	373	0	3494
	Total	4	1033	4679	5605	2209	27	13557

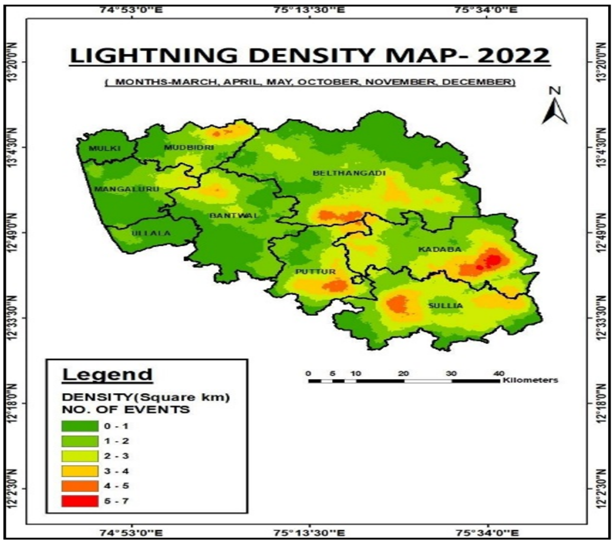

Figure 7. Lightning density map of Dakshina Kannada in 2022.

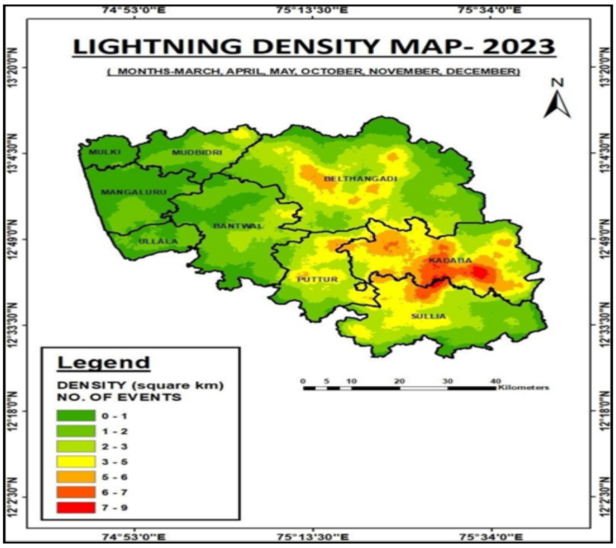

Figure 8. Lightning density map of Dakshina Kannada in 2023.

Seasonal variations

The analysis of seasonal variations reveals significant differences in lightning occurrences between pre-monsoon (March-May) and post-monsoon (October-December) periods. The pre-monsoon season consistently exhibited higher lightning activity across all three years. In 2021, the pre-monsoon period accounted for 38,601 lightning incidents, while the post-monsoon period recorded only 10,350 incidents [29,30] (Figure 9).

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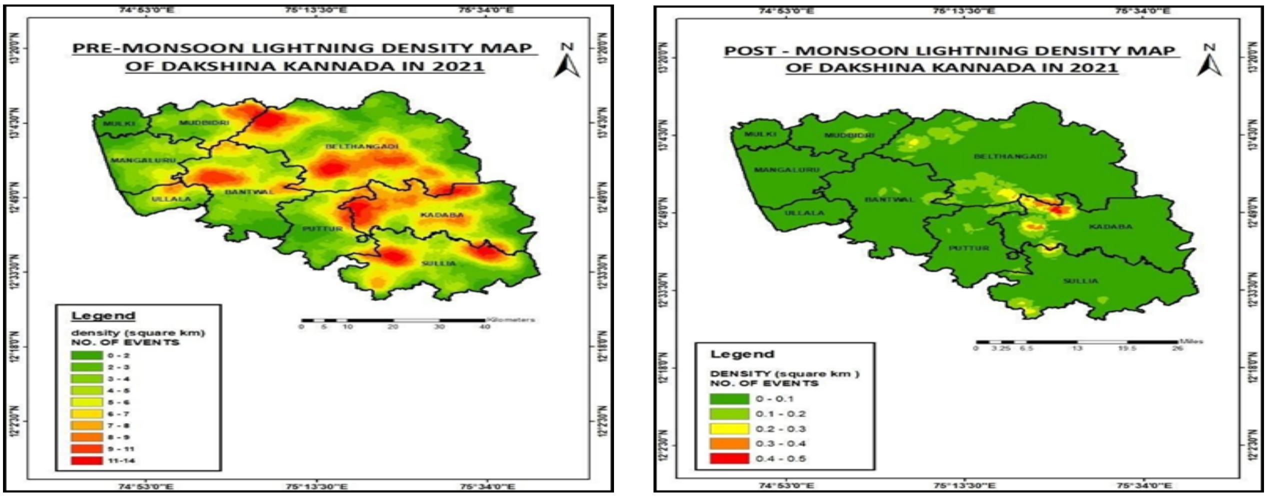

Figure 9. Pre-monsoon and Post-monsoon 2021.

Similarly, in 2022, the pre-monsoon season showed more activity, with densities of 4-7 strikes per square kilometer, compared to 1-1.5 strikes per km² during the post- monsoon period (Figure 10).

In 2023, while the total number of incidents remained lower than in 2021, the pattern of higher pre-monsoon activity persisted, with 3-6 strikes per km² compared to 3-5 per km² in the post-monsoon season (Figures 11) [29].

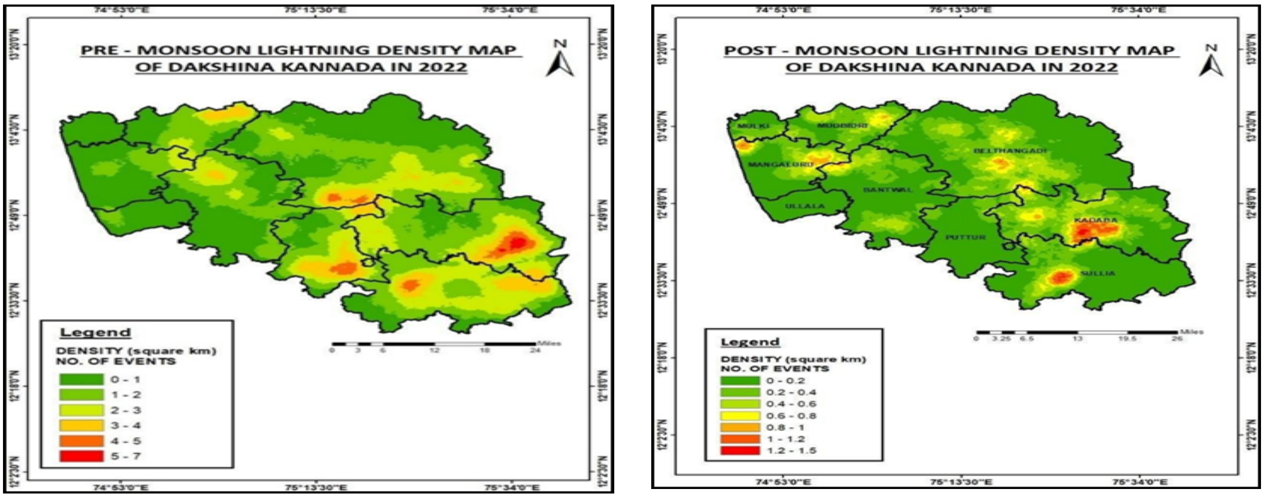

Figure 10. Pre-monsoon and Post-monsoon 2022.

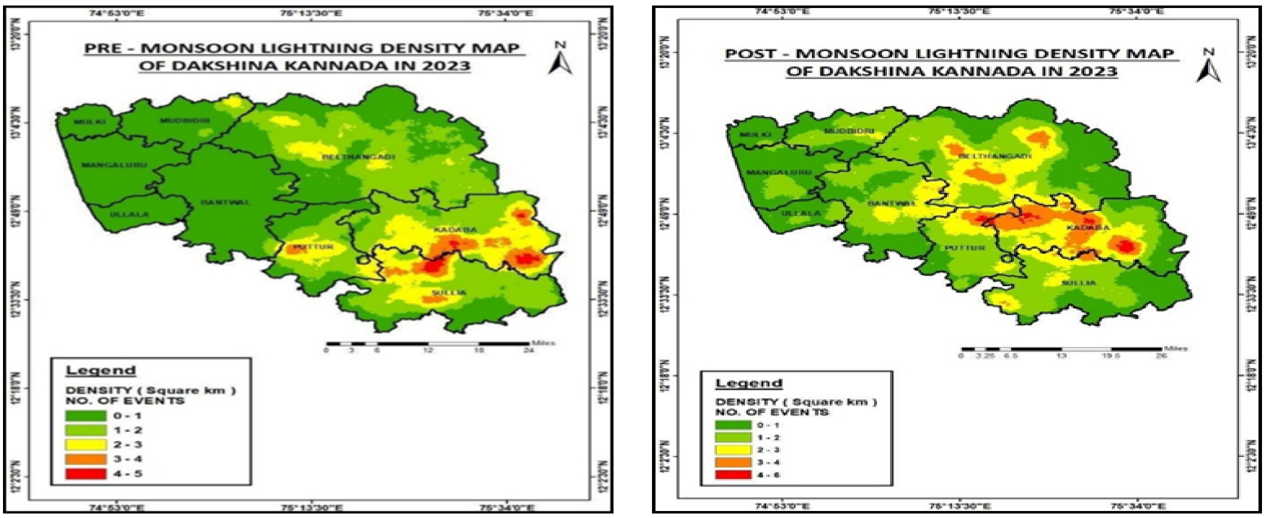

Figure 11. Pre-monsoon and Post-monsoon 2023.

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These patterns suggest that the pre-monsoon season is characterized by conditions that favor lightning formation, including higher solar radiation, increased moisture transport from the surrounding seas, and atmospheric instability. In contrast, the post-monsoon period experiences lower levels of solar heating and reduced moisture availability, resulting in fewer lightning strikes [31].

LULC Correlation

The correlation between lightning strikes and different Land Use and Land Cover (LULC) types was analyzed using spatial overlays of LULC data and lightning density maps (Figures 12-14). The analysis indicates that areas with mixed LULC types, such as forests, agricultural lands, and built-up areas, tend to experience higher lightning activity. Taluks like Kadaba, Belthangadi, and Sullia, which feature a combination of forested areas and agricultural land, consistently recorded high lightning densities over the three years [32].

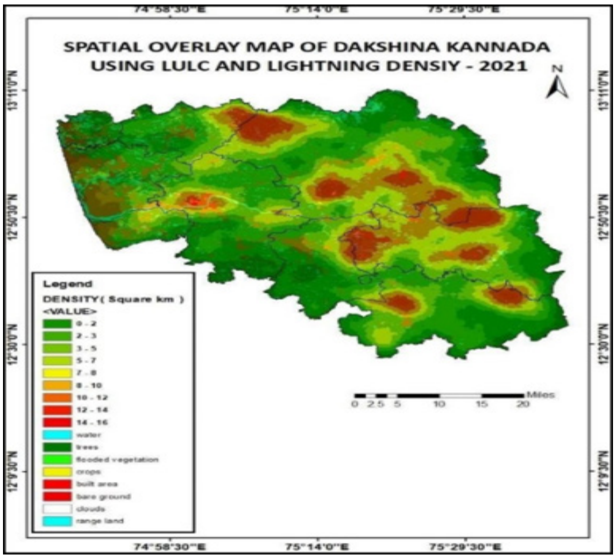

Figure 12. Spatial Overlay Using LULC and Lightning Density map-2021.

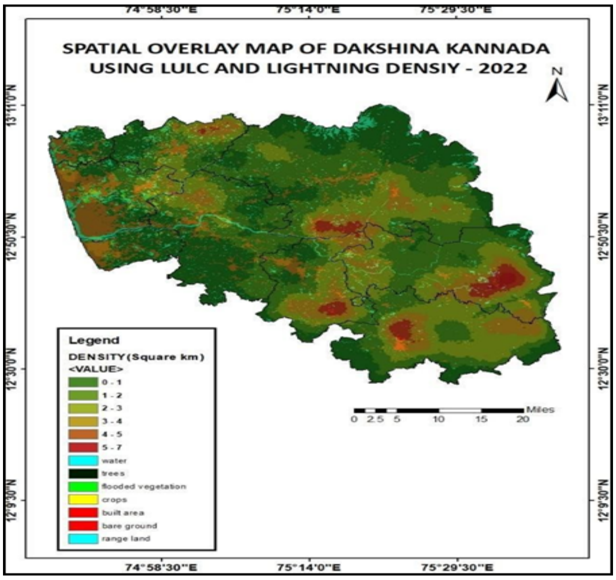

Figure 13. Spatial Overlay Using LULC and Lightning Density map-2022.

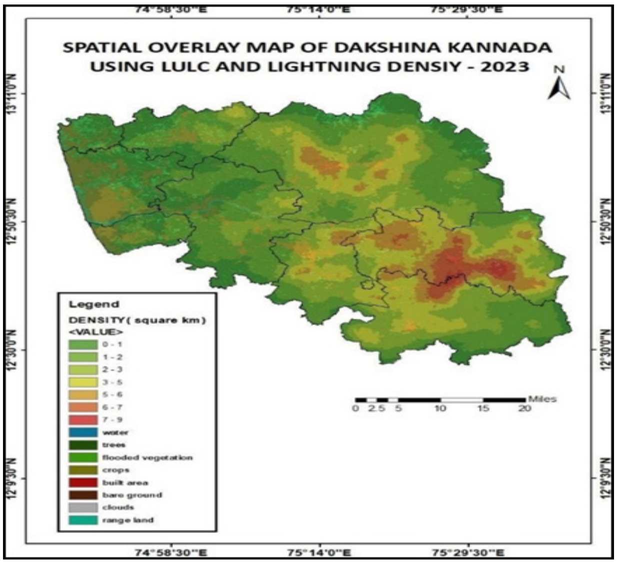

Figure 14. Spatial Overlay Using LULC and Lightning Density map-2023.

Forested areas, particularly those with tall trees and high moisture content, are more susceptible to lightning strikes due to their ability to conduct electricity. Similarly, built-up areas contribute to increased lightning activity due to the urban heat island effect, where urban structures absorb and retain heat, causing localized warming. The spatial overlay maps further illustrate that the Western Ghats region amplifies lightning risks due to orographic effects, where moist air is forced upward by the elevated terrain, promoting cloud formation and electrical discharge [33].

Visualization

The study findings are visually represented through various maps, graphs, and charts. Choropleth maps (Figures 15-17) illustrate the spatial distribution of lightning incidents across Dakshina Kannada's taluks for each year.

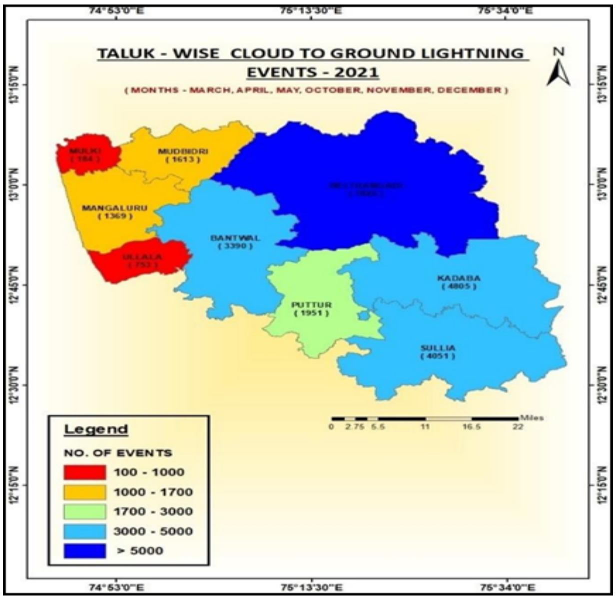

Figure 15. Choropleth map of DK in 2021.

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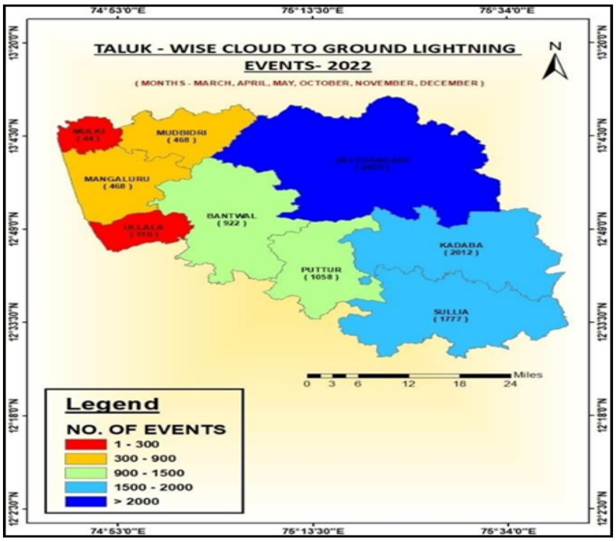

Figure 16. Choropleth map of DK in 2022.

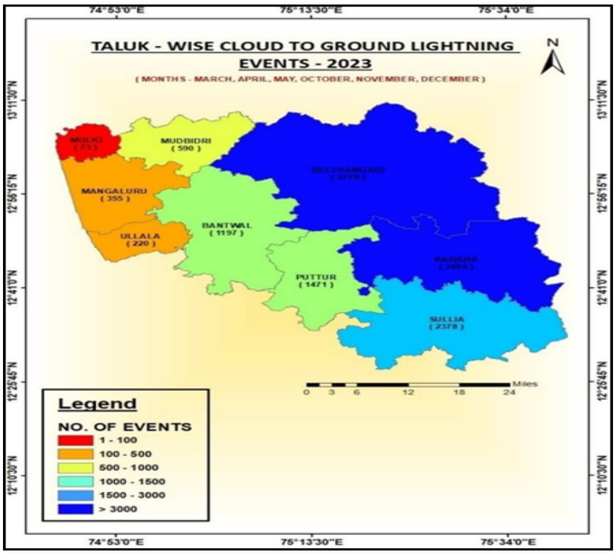

Figure 17. Choropleth map of DK in 2023.

Density maps highlight specific hotspots with high lightning activity, while seasonal variation graphs (Figures 18 and 19) depict differences in lightning occurrences between pre-monsoon and post-monsoon periods [12].

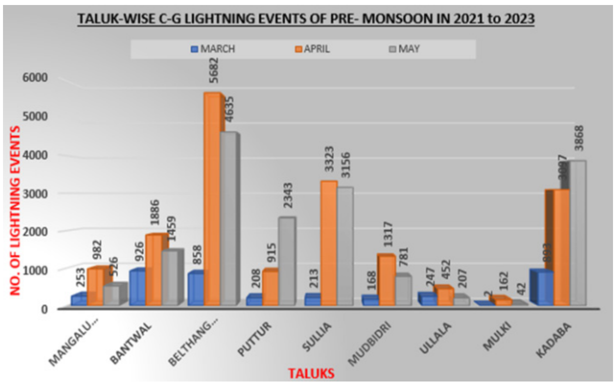

Figure 18. Bar graph of pre-monsoon C-G lightning events from 2021-2023.

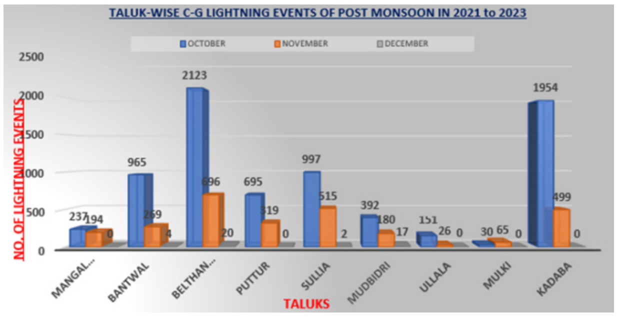

Figure 19. Bar graph of Post–monsoon C-G lightning events from 2021-2023.

The spatial overlay maps combine LULC and lightning density data, providing a comprehensive view of the correlation between land use types and lightning strikes.

Discussion

Comparison with existing studies

The findings of this study are consistent with previous research on lightning patterns in the Western Ghats region and other areas with complex terrain. Ranalkar & Chaudhari (2009) reported increased lightning activity in regions where orographic lifting contributes to cloud formation and electrical discharge [34]. Similarly, Chakraborty et al. (2021) found that lightning density is typically higher in areas with significant elevation changes and varied land cover, such as forests and urban zones [35].

However, this study also identifies some deviations from previous findings. For example, while Kamra and Nair (2015) identified a single afternoon peak in lightning flash density, our study reveals that lightning activity peaks multiple times during the pre-monsoon and post-monsoon periods, depending on local climate and regional factors. This finding implies that local factors have an important role in producing lightning patterns, underlining the necessity for region-specific studies [9].

Interpretation of results

The findings show that meteorological and topographical factors greatly influence lightning dispersion in Dakshina Kannada. The Western Ghats, which run parallel to India's west coast, have a significant impact on local weather patterns. This mountain range acts as a barrier, causing moist air from the Arabian Sea to ascend, resulting in cloud formation and enhanced lightning activity known as orographic lifting. This effect is especially noticeable during the pre-monsoon season, when the temperature difference between land and sea is at its highest [36].

The association between LULC types and lightning strikes lends credence to the concept that environmental and anthropogenic variables work together to shape the region's lightning patterns. Forested locations with tall trees and high moisture content, as well as built-up zones that form localized heat islands, are more likely to see lightning strikes. These findings highlight the need of considering both natural landscape features and human development patterns when estimating lightning danger [37].

Implications for disaster management

The study's findings have important implications for disaster management and risk mitigation in Dakshina Kannada.

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Identifying high-risk locations, such as Kadaba, Belthangadi, and Sullia, enables local governments to concentrate their efforts on these areas, resulting in better planning and resource allocation. Improving early warning systems in these locations can assist to mitigate the impact of lightning-related occurrences by sending timely signals to inhabitants and emergency responders. Public education efforts should target high-risk zones to raise community knowledge and readiness, especially during the most vulnerable months [38].

Furthermore, the spatial overlay maps shed light on the relationship between LULC changes and lightning activity, which informs land use planning and zoning rules. Maintaining or growing forest cover in high-risk locations could help alleviate the impacts of lightning strikes, and careful urban development planning should minimize the establishment of urban heat islands, which contribute to increased lightning activity [39].

Limitations and future research

While this study provides a complete investigation of lightning patterns in Dakshina Kannada, it has several limitations. The lightning data's resolution and temporal scope (2021-2023) may not capture all of the elements impacting lightning activity in the region. Furthermore, the study largely focuses on cloud-to-ground lightning, disregarding other forms of lightning events that may affect the area [40].

Future research could build on this work by include real-time lightning data and investigating the effects of climate change on regional lightning patterns. Further research might also look into the socioeconomic consequences of lightning strikes, such as property and infrastructure damage, and create more refined models to predict lightning activity based on meteorological and environmental variables [39].

Conclusions

This study examines the considerable spatiotemporal variation of cloud-to-ground lightning strikes in Dakshina Kannada from 2021 to 2023, identifying critical locations of high lightning activity, particularly in the pre-monsoon months of April and May. The study cites Kadaba, Sullia, Belthangadi, and Bantwal taluks as major lightning hotspots, owing to their topography and the orographic effect of the Western Ghats. The study found that wooded locations with tall, moisture-laden trees are more prone to lightning strikes, whereas urban areas had lower density. The work improves our understanding of lightning distribution in the Dakshina Kannada area by combining GIS and remote sensing tools to correlate lightning density with Land Use and Land Cover (LULC) patterns. This research provides significant information for disasters.

To improve preparedness and resilience, local governments should build early warning systems and conduct public education campaigns, particularly in designated hotspots. Strengthening infrastructure, such as putting lightning rods in high-risk regions and enhancing monitoring systems, can help reduce the hazards connected with lightning strikes. Future research should also look into how urbanization and climate change affect lightning activity.

Disclosure statement

No potential conflict of interest was reported by the authors.

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